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EFFECT OF AN INTERMEDIATE LAYER OF GYPSUM ON THE SHEAR RESPONSE OF SHEATHING-TO-STUD NAILED WOOD CONNECTIONS

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ABSTRACT: The primary lateral force resisting mechanism in light-frame timber shear walls consists of plywood or oriented strand board sheathing that is typically nailed to the framing elements in the wall. Such shear walls often have sheathing on only one side and a layer of gypsum board for interior finishing on the other side. In retrofit applications, it may be desirable to increase the strength of such a wall by adding an additional layer of sheathing to the interior surface of the wall overtop of the gypsum. The current study investigated the effect that such an intermediate gypsum layer has on the shear strength and stiffness of a nailed shear wall connection. Individual nailed joints were tested with and without gypsum as an intermediate layer. A code-based minimum nail embedment depth into the stud was maintained in the tests. The results showed that gypsum placed in between the stud and sheathing significantly decreased both the stiffness (by up to 83%) and the strength (by up to 62%) of the joint. This suggests that it is not conservative to add a layer of sheathing over an existing layer of gypsum without reducing the effective strength of the wall, even if minimum nail embedment is met.

1. Introduction

Light-frame wood structures are popular in Canada and across North America, especially for residential construction. The primary advantages of this type of timber construction are that it is easy to construct, lightweight, and sustainable. Light frame wood structures consist primarily of floors, walls, roof, and partition walls, which are made of sheathed dimensional lumber members held together, typically, by nails.

Lateral loads on a light-frame wood structure are typically resisted by wood light frame shear walls, which consist of framing elements (wall studs, top and bottom plates) connected to sheathing panels. Shear walls constructed with wood-based sheathing panels: i.e. oriented strand board (OSB) or plywood provide higher capacity than those sheathed with gypsum wallboard (GWB).

The primary source of ductility and energy dissipation in a light-frame shear wall is the yielding of the nailed connections between the sheathing and framing. The nails that connect the sheathing and framing are typically spaced at 50 to 200 mm intervals, and consist of size 6d, 8d or 10d nails. The strongest configuration for such connections occurs when the sheathing panel is in direct contact with the framing; however, current code provisions permit the inclusion of an intermediate panel of GWB with a thickness of 12.7 or 15.9 mm (1/2" and 5/8") between the sheathing and framing, provided that minimum nail penetration limits are met (CSA, 2014).

The ability to include such an intermediate layer of gypsum may be useful in seismic or wind retrofit situations where existing exterior or interior partition walls are strengthened or converted into shear walls through the addition of a layer of wood based sheathing.

In the Canadian design standard, the limit on the minimum nail penetration for light frame shear walls has recently changed (CSA, 2014). The 2009 standard used values of minimum nail penetration of approximately 11 times the nail diameter (31, 38, and 41 mm for 6d, 8d, and 10d nails, respectively) (CSA,2009), which is also consistent with Keith & Skaggs (APA, 1998). The more recent 2014 standard has relaxed this limit to 6 times the nail diameter, bringing it into harmony with the minimum penetration for a general nailed connection (CSA, 2014). All of the nailed connection tests considered in this study met the limits of the 2014 standard. If the minimum nail penetration is met, both versions of the standard stipulate that a shear wall with wood sheathing over GWB has equivalent capacity as one with the same wood sheathing directly attached to the stud (without intermediate GWB).

To the author's knowledge, this issue has not been investigated; however one study by Tissell (1993) investigated full-scale shear walls that included an intermediate layer of GWB. In that study, a total of eight full-scale shear walls with an intermediate layer of GWB between the sheathing and the stud were tested. The study considered the following parameters: fastener type, fastener size, fastener spacing, sheathing type and GWB thickness. Results from this study suggested that shear walls with intermediate GWB provided enough ultimate load to be considered safe for use. The objective of that study was to verify that particular configurations for shear walls with intermediate GWB were safe, rather than to isolate the effect of intermediate GWB on strength and stiffness in detail. Therefore, no control case without GWB was tested, making evaluation of the effect of added GWB difficult.

The objective of the current study is to investigate light-frame wood shear wall connections built with and without an intermediate layer of GWB with regard to strength and stiffness, and to assess the results in the context of current code provisions. For these purposes, individual nailed connection specimens representing the shear connection between a stud and sheathing (with and without an intermediate layer of GWB) were tested.

2. Specimen Setup

Thirty-six connection specimens with intermediate layer of GWB and eighteen specimens without GWB (i.e. the control specimens) were tested in this study. A schematic of a typical specimen that includes GWB is shown in Figure 1. The specimens were designed for the application of pure shear loading on four nails, which constitute the connection between the stud, the element in the middle of the specimen, and the sheathing elements.

The stud framing element in the center of the specimen shown in Figure 1 is a cut section of 38x140 mm (2"x6") No.2 grade SPF (spruce-pine-fir) lumber member. Adjacent to the stud framing element, a layer of GWB with thicknesses of either 12.7 mm and 15.9 mm (1/2" and 5/8") was used. The outer layers on either side of stud consisted of a sheathing layer of oriented strand board (OSB) with thicknesses of either 11.1 mm or 15.9 mm. Nail sizes were 6d, 8d, and 10d with diameters of 2.84, 3.25, and 3.66 mm, respectively, and lengths of 51, 64, and 76 mm, respectively.

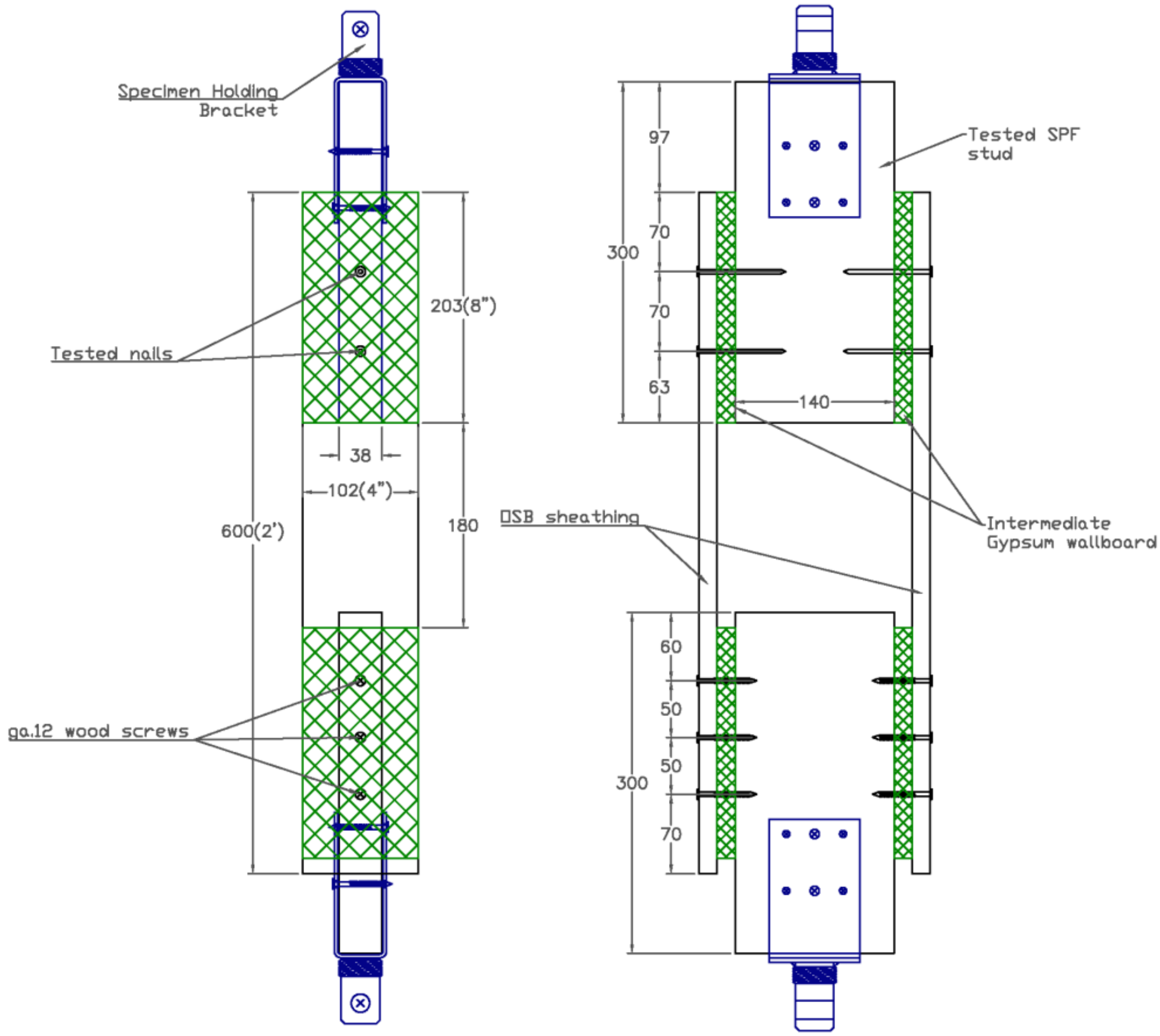

Fig. 1 – Test Specimen

The testing apparatus featured a displacement measurement mechanism consisting of two string potentiometers, which recorded the local displacement of the nailed connection between the stud and the sheathing on either side. Displacement was applied at a rate of 2.5 mm/min in conformance with ASTM F1667, up to a final displacement of 27.5 mm, at which point all tests were stopped.

Test specimens were fabricated with most commonly used nail sizes and three intermediate GWB thicknesses conditions: no GWB, 1/2" GWB (12.7 mm), and 5/8" GWB (15.9 mm) giving a total of 9 combinations as shown in Table 1. Six identical replicates of each combination were constructed and tested.

Table 1 – Testing Matrix

GWB thickness	Sheathing thickness	Nail size	Nail Penetration in Framing (mm)
0mm (0")	11.1 mm (7/16")	6d	39.7
0mm (0")	11.1 mm (7/16")	8d	52.4
0mm (0")	15.9 mm (5/8")	10d	60.3
12.7mm (1/2")	11.1 mm (7/16")	6d	27.0
12.7mm (1/2")	11.1 mm (7/16")	8d	39.7
12.7mm (1/2")	15.9 mm (5/8")	10d	47.6
15.9mm (5/8")	11.1 mm (7/16")	6d	24.2
15.9mm (5/8")	11.1 mm (7/16")	8d	36.9
15.9mm (5/8")	15.9 mm (5/8")	10d	44.8

3. Experimental Results

The load-deformation response for all six identical tests was averaged, and divided by 4 to express the behaviour of each single nail. Figures 2a, 2b, and 2c show the load-deformation response per nail for tests with 6d, 8d, and 10d nails, respectively. Each line shows the mean response of an individual nail with a specific thickness of intermediate GWB.

It is clear from the load-deformation behaviour of all three nail size cases that there is a substantial drop of approximately 40-50% of connection ultimate load with the introduction of an intermediate layer of GWB of any size. There is also a clear change in the initial stiffness and amount of deformation at which the ultimate load occurs. Connections with intermediate GWB were observed to reach their ultimate capacity at much higher displacement levels compared to the control case. Since the ultimate displacement was limited by the test apparatus to 27.5 mm, the ultimate capacity for some tests occurred beyond this limit and was therefore not observed, as seen in the case of 12.7 mm of GWB with 8d nails, in Figure 3.

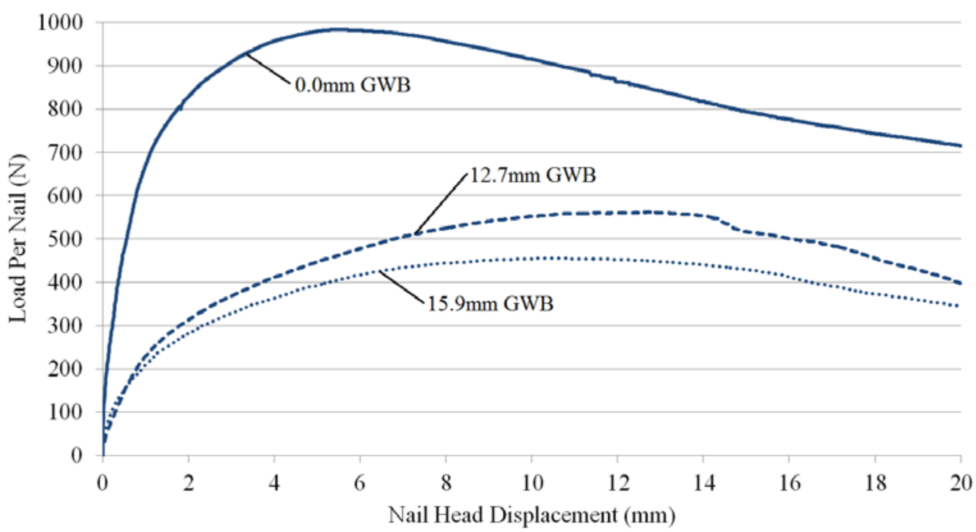

Fig. 2a – Shear load-deformation behaviour for specimens with 6d nails

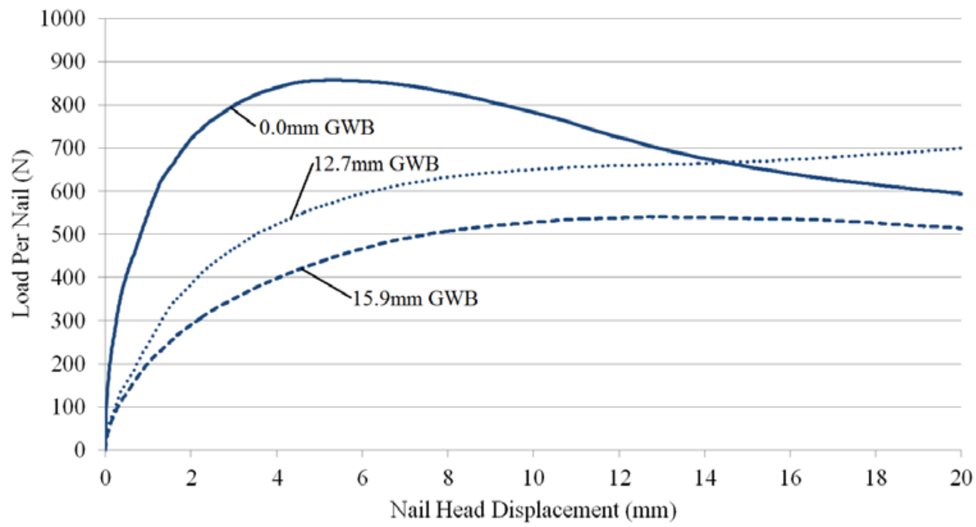

Fig. 2b – Shear load-deformation behaviour for specimens with 8d nails

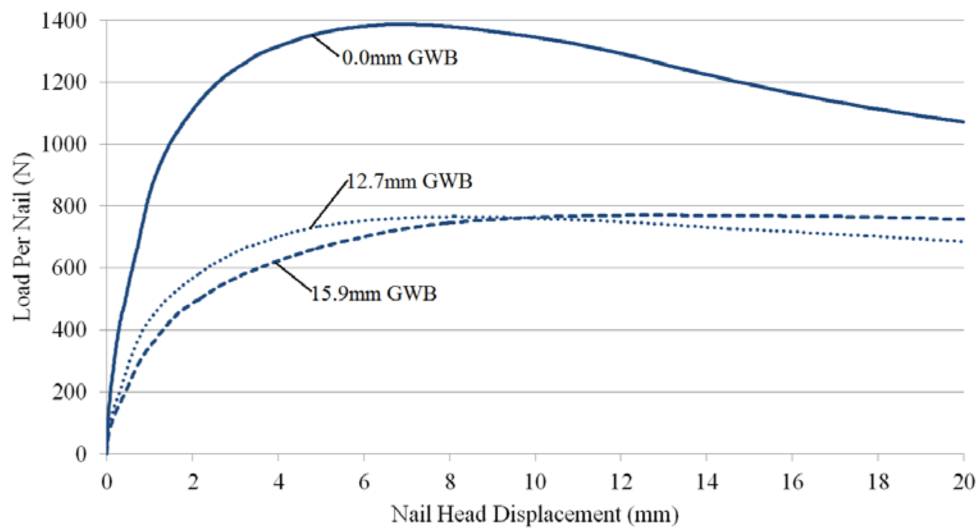

Fig. 2c – Shear load-deformation behaviour for specimens with 10d nails

Table 2 shows the peak load for each tested condition, as well as the coefficient of variation based on the six test repetitions for each specimen type. This data shows that, relative to the tests with no intermediate GWB, there is a significant decrease in nailed connection strength when an intermediate layer of GWB is added. The magnitude of this drop is in the order of 40-50% for most of the connections with added GWB of either thickness. No clear difference was observed between specimens with 12.7 mm and 15.9 mm GWB.

Table 2: Comparison of peak connection shear capacity and COV (for a single nail)

Gypsum Wallboard Thickness	6d Nail			8d Nail			10d Nail		
	Mean (N)	COV	Rel. to Control	Mean (N)	COV	Rel. to Control	Mean (N)	COV	Rel. to Control
0" (Control)	986	0.19	100%	863	0.32	100%	1390	0.25	100%
1/2" (12.7 mm)	489	0.29	50%	703	0.21	81%	769	0.12	55%
5/8" (15.9 mm)	583	0.20	59%	557	0.18	65%	779	0.10	56%

4. Yield Point Calculation

In addition to the peak strength of the connections, for seismic design it is useful to have a measure of the shear force in the nailed connections when they start to yield. However, as can be seen in Figures 2a to 2c, there is no clear demarcation point on the load deformation curves that shows when yielding has occurred. Munoz et al. (2008) have compiled a review of the most common methods of calculating the yield point of nailed connections. Of these methods, five were selected for use in this study to estimate the yield force of the connections. These methods are summarized in Figure 3.

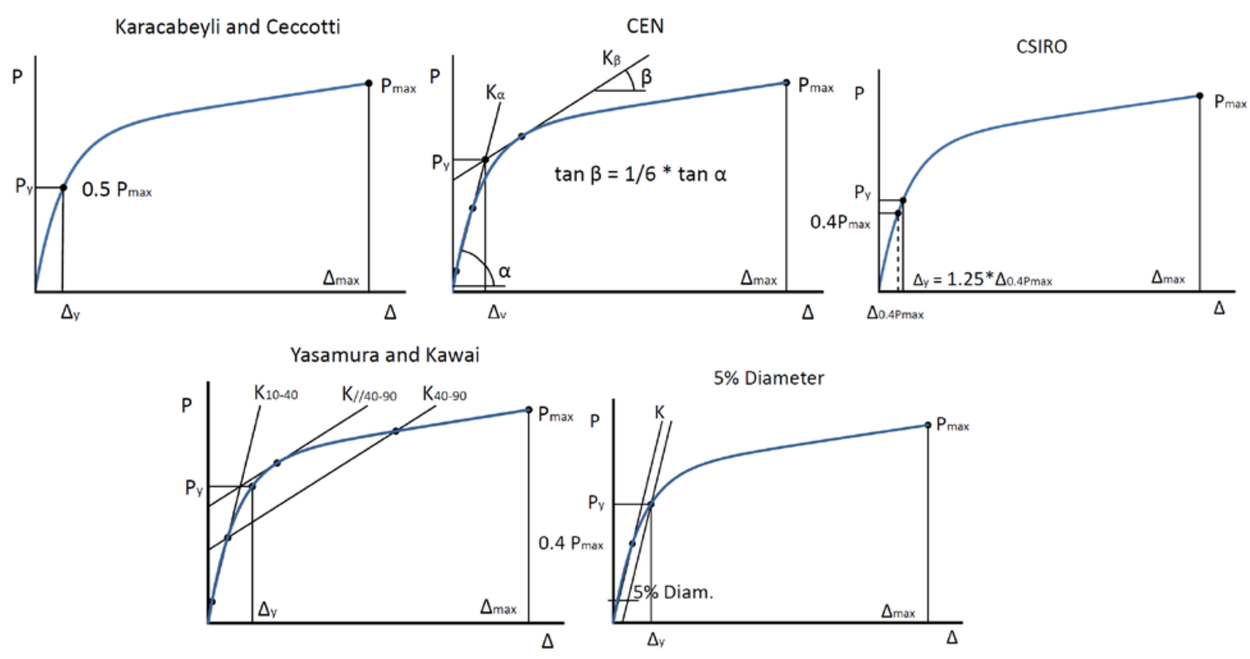

Fig. 3 – Yield point calculation methods (after Munoz et al. 2008)

The use of any of these methods requires knowledge of the ultimate capacity as an input. For those cases where a clear peak load was not reached, the maximum load recorded at the end of the test was deemed sufficiently close to the ultimate capacity and was therefore used for estimating the yield point. Figure 4 compares the estimated yield strength and secant stiffness (stiffness up to the yield point) for each method from Figure 3. This data is plotted against the nail penetration distance for each test. The error bars for each graph show one standard deviation based on the results from the six identical tests.

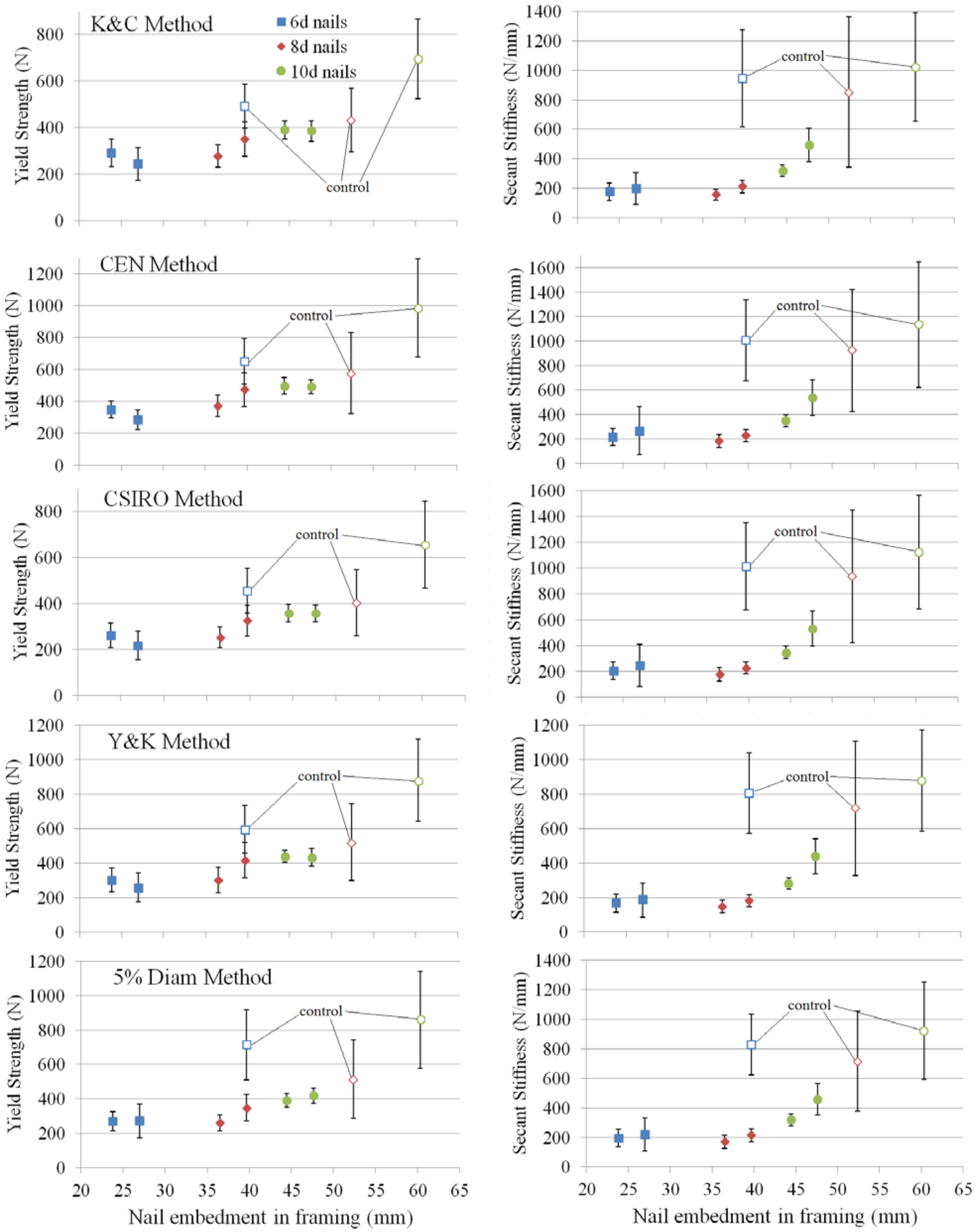

Fig. 4 – Yield point of experimental tests

Less variability is observed in specimens with an intermediate layer of GWB versus control specimens. A likely explanation for this is that there is more variability in the physical properties of the framing wood than there is in the nail steel. Control cases with no intermediate GWB resulted in a characteristically S-shaped post-failure nail shape, which is influenced more by crushing of the wood members than those with intermediate GWB. A nail within a connection with an intermediate material tends to deform like a simple cantilever, and, consequently, the strength and stiffness of the connection is more dependent on bending in the nail. Since steel has less variability in material properties, these connections with intermediate GWB show less variability in the test results.

From these results, it is clear that when an intermediate layer of GWB is added to the connection, there is a significant decrease in yield strength, regardless of the selected calculation method. All of the methods show a similar trend. The results in Fig. 4 also show that there is a clear and significant decrease in stiffness when GWB is added to the connection.

Table 3 summarizes the strength of the connections using a subset of the yield estimation methods previously discussed: (i) the K&C method (the most optimistic of the 5 yield point estimation methods, resulting in the lowest overall loss of connection capacity); and (ii) the 5% diameter method (the most pessimistic of the 5 yield point methods), as well as the maximum recorded capacity. Regardless of the experimental case or calculation method, introduction of an intermediate layer of GWB of either permitted size results in a loss of both capacity and yield load of roughly -40% to -50%.

Table 3: Comparison of drop in shear strength using various methods

Nail Size	GWB Thickness	Maximum Load (reduction relative to control), (N)		
		Capacity	Yield Strength	
		Recorded Maximum	K&C Method	5% Diameter Method
6d	None	985.6	492.8	713.5
6d	1/2" (12.7 mm)	488.6 (-50%)	244.3 (-50%)	272.7 (-62%)
6d	5/8" (15.9 mm)	582.7 (-41%)	291.3 (-41%)	270.0 (-62%)
8d	None	863.4	431.7	514.6
8d	1/2" (12.7 mm)	702.6 (-19%)	351.3 (-19%)	348.3 (-32%)
8d	5/8" (15.9 mm)	556.7 (-35%)	278.4 (-35%)	261.7 (-49%)
10d	None	1389.6	694.8	859.2
10d	1/2" (12.7 mm)	768.5 (-45%)	384.3 (-45%)	417.3 (-51%)
10d	5/8" (15.9 mm)	779.2 (-44%)	389.6 (-44%)	391.5 (-54%)

Table 4: Comparison of drop in stiffness using various methods

Nail Size	GWB Thickness	Stiffness (reduction relative to control), (N/mm)		
		10-40% capacity stiffness	5% Diameter Method	K&C Method
6d	None	890.4	830.8	946.8
6d	1/2" (12.7 mm)	226.8 (-74%)	220.8 (-73%)	199.1 (-79%)
6d	5/8" (15.9 mm)	193.7 (-78%)	195.7 (-76%)	177.1 (-81%)
8d	None	802.5	715.3	854.6
8d	1/2" (12.7 mm)	206.5 (-74%)	216.0 (-70%)	213.1 (-75%)
8d	5/8" (15.9 mm)	162.6 (-80%)	171.3 (-76%)	158.5 (-81%)
10d	None	1021.8	922.6	1023.2
10d	1/2" (12.7 mm)	486.4 (-52%)	457.6 (-50%)	495.4 (-52%)
10d	5/8" (15.9 mm)	310.5 (-80%)	319.5 (-65%)	320.4 (-69%)

Table 4 summarizes the shear stiffness of the connection calculated using three different methods: (i) mean stiffness calculated based on the load-deformation response between 10% and 40% of the maximum recorded load; (ii) secant stiffness from the K&C method (the most pessimistic method); and (iii) secant stiffness from the 5% diameter method (the most optimistic method). Regardless of the experimental case or calculation method, introduction of an intermediate layer of GWB of either permitted size resulted in a loss of stiffness of approximately -70% to -80%. Overall, higher relative losses were observed with smaller nails.

These results for strength and stiffness suggest that the current recommendations of the Canadian design standard with regard to the use of intermediate GWB between studs and sheathing in light frame shear walls may not be appropriate.

5. Conclusions

Based on the results of this study, the introduction of a 12.7 mm or 15.9 mm (1/2" or 5/8") intermediate layer of GWB between the stud and sheathing in a nailed connection, even while maintaining minimum nail penetration in accordance with CSA-O86-14, may result in a loss of up to 62% of connection strength and up to 83% of connection stiffness. Given that a light frame shear wall is highly dependent on individual nailed connections between sheathing and framing, the timber design standard does not seem to be conservative. Therefore, it is recommended that the Canadian design standard allowances for connections with an intermediate layer of GWB should not be used as currently written.

These results should be confirmed in future using additional full-scale shear wall tests. Such testing on a large number of walls would better quantify the strength and stiffness losses observed when an intermediate layer of GWB is used.

6. References

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